REINFORCED FAN BLADE AND METHOD OF MAKING

BACKGROUND OF THE INVENTION

[0001] The invention relates to fan blades and in particular to fan blades reinforced with a high elongation fiber composite.

[0002] Fan blades used in jet engine applications are susceptible to foreign object impact damage such as bird ingestion events. Blades made of graphite fiber reinforced composite material are attractive due to their high overall specific strength and stiffness. However, graphite composites are particularly prone to brittle fracture and delamination during foreign object impacts due to their low ductility. Blade leading edges, trailing edges, and tips are particularly sensitive because of the generally lower thickness in these areas and the well-known susceptibility of laminated composites to free edge delamination. In addition blade geometry and high rotational speeds relative to aircraft speeds cause ingested objects to strike the blade near the leading edge. The material near the suction and pressure surfaces of the composite are most prone to fracture due to the local bending deformations typically associated with such events.

[0003] Metallic guards bonded to the composite blade are known to provide impact damage protection. However, the high density of these materials limit their use. In addition, blades can be ruggedized by increasing the airfoil thickness either locally or over a wide area. Blade thickening results in an aerodynamic penalty as well as a weight penalty.

BRIEF DESCRIPTION OF THE INVENTION

[0004] An aspect of the invention is a fan blade comprising a plurality of fiber composite layers and at least one high elongation fiber composite strip joining one of said fiber composite layers at a joint.

[0005] Another aspect of the invention is a method of forming a fan blade. A method of making a fan blade includes joining a plurality of fiber composite layers

and joining at least one high elongation fiber composite strip to one of the plurality of fiber composite layers. An end of the high elongation fiber composite strip meets an end of the fiber composite layer at a joint.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] Referring to the exemplary drawings wherein like elements are numbered alike in the several Figures:

[0007] Figure 1 is an exemplary fan blade;

[0008] Figures 2 and 3 are cross-sectional views of a leading edge of a fan blade in an embodiment of the invention;

[0009] Figure 4 is a cross-sectional view of a leading edge of a fan blade in another embodiment of the invention;

[0010] Figure 5 is a cross-sectional view of a leading edge of a fan blade in another embodiment of the invention;

[0011] Figure 6 is a cross-sectional view of a leading edge of a fan blade in another embodiment of the invention;

[0012] Figures 7-10 are cross-sectional views of fan blades depicting reinforcement placement in embodiments of the invention;

[0013] Figure 11 is a cross-sectional view a leading edge of a fan blade in another embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0014] Embodiments of the invention relate to reinforced, fiber composite fan blades. Such fan blades may be used in a variety of applications including jet engines, turbines, etc. The fiber composite may be a material having any (metal or non-metal) fiber filament embedded in any (metal or non- metal) matrix binder. In one embodiment of the invention, the majority of the fan blade is a lay-up of discrete

fiber composite laminations. In an exemplary embodiment, the fiber composite is comprised of graphite fiber filaments embedded in an epoxy (e.g., epoxy resin) matrix binder with the resulting composite layer having an elastic modulus of between 124,110 megapascals (MPa) and 165,480 megapascals (MPa) and tensile elongation of between 1.3 % and 1.5 %, both measured parallel to the fibers. Other choices for the matrix resin include, but are not limited to, bismaleimide, polyimide, polyetherimide, polyetheretherketone, poly(aryl sulfone), polyethersulfone and cyante ester and combinations thereof. In one embodiment the matrix binder includes toughening materials such as rubber particles.

[0015] The fiber composite fan blades are reinforced with a high elongation fiber composite. In one embodiment, the modulus of the high elongation fiber composite may range from about 13,790 MPa to about 96,530 MPa and is preferably from about 41,370 MPa to about 62,055 MPa. The tensile elongation of the high elongation fiber composite should be at least about 1.75%, and is preferably at least about 3%. Exemplary high elongation fiber composites include S-glass, aramid, extended-chain polyethylene, and poly(p-phenylenebenzobisoxazole) (PBO).

[0016] Figure 1 is a perspective view of a fan blade 10 in an embodiment of the invention. Fan blade 10 has a leading edge 12 and a trailing edge 14. The fan blade also has a first side 16 and a second side 18 that extend between the leading edge to the trailing edge. Additional components such as guards or coatings m ay be applied to the first and second side 16 and 18 as described in further detail with reference to Figure 11. As known in the art, the majority of fan blade 10 is made from fiber composite layers (e.g., carbon fiber layers) extending between the leading edge 12 and the trailing edge 14. The fiber composite layers extend chordwise from leading edge 12 to trailing edge 14 and spanwise from a root 11 to a tip 13.

[0017] Fan blade 10 is reinforced with high elongation fiber composite strips in areas prone to damage. Typically these are blade leading edges, tips, and trailing edges and distributed toward the pressure and suction surfaces of the blade. The high elongation fiber composite strips allow fan blade 10 to deform greatly prior to failure

and also results in the load being distributed over a larger area, making local damage less likely.

[0018] Figure 2 is a cross-sectional view of a leading edge 12 of fan blade 10. A number of high elongation fiber composite strips 20, 22 and 24 are used to reinforce the leading edge. The strips extend from leading edge 12 towards trailing edge 14 and extend inward from the outer surfaces of sides 16 and 18. A section 26 of the composite fiber is left exposed at the leading edge 12. The high elongation fiber composite strips have fibers arranged in different orientations. High elongation fiber composite strips 20 have fibers oriented in a direction parallel to the spanwise direction of the blade 10. High elongation fiber composite strips 22 have fibers oriented in a direction 45 degrees relative to the spanwise direction of the blade 10. High elongation fiber composite strips 24 have fibers oriented in a direction -45 degrees relative to the spanwise direction of the blade 10.

[0019] Figure 3 shows fiber composite layers 30 relative to the high elongation fiber composite strips 20, 22 and 24. The ends of the high elongation fiber composite strips 20, 22 and 24 distanced from leading edge 12 are staggered. That is, the length of each high elongation fiber composite strips decreases as position from surface of sides 16 and 18 increases. In one embodiment, the difference d in length between adjacent high elongation fiber composite strips is at least about 0.1 inches. Alternatively, the difference d may be expressed as a function of strip thickness and in an embodiment, is at least 15 times the strip thickness. This tapers the high elongation fiber composite strips such that the compliant region is longer near the pressure and suction surfaces than in the middle of the fan blade.

[0020] The high elongation fiber composite strips 20, 22 and 24 meet the fiber composite layers 30 at a joint. The joint may be a butt joint or a small overlap. The high elongation fiber composite strips 20, 22 and 24 may be incorporated in blade 10 during the layup process in which layers of fiber composite and high elongation fiber composite are adhesively bonded or co-cured. The fan blade 10 is constructed from the interior outwards to the first side 16 and second side 18. The fiber composite layers 30 are joined using techniques such as adhesives or co-curing. Once

the reinforcement locations are reached, strips of high elongation fiber composite are joined to the layers of fiber composite using techniques such as adhesives or co-curing.

[0021] Figure 4 is a cross-sectional view of a leading edge 12 of fan blade 10 in an alternate embodiment. In the embodiment of Figure 4, the high elongation fiber composite strips 20, 22 and 24 wrap around leading edge 12 to cover the leading edge. High elongation fiber composite strips 20 have fibers oriented in a direction parallel to the spanwise direction of the blade 10. High elongation fiber composite strips 22 have fibers oriented in a direction 45 degrees relative to the spanwise direction of the blade 10. High elongation fiber composite strips 24 have fibers oriented in a direction -45 degrees relative to the spanwise direction of the blade 10. The high elongation fiber composite strips 20, 22 and 24 meet the fiber composite layers at a joint as described above with reference to Figure 3.

[0022] Figure 5 is a cross-sectional view of a leading edge 12 of fan blade 10 in an alternate embodiment. In the embodiment of Figure 5, the ends of the high elongation fiber composite strips 20, 22 and 24 are staggered such that adjacent high elongation fiber composite strips may have different lengths, but the lengths do not decrease as position from surface of sides 16 and 18 increases. High elongation fiber composite strips 20 have fibers oriented in a direction parallel to the spanwise direction of the blade 10. High elongation fiber composite strips 22 have fibers oriented in a direction 45 degrees relative to the spanwise direction of the blade 10. High elongation fiber composite strips 24 have fibers oriented in a direction -45 degrees relative to the spanwise direction of the blade 10. The high elongation fiber composite strips 20, 22 and 24 meet the fiber composite layers at a joint as described above with reference to Figure 3.

[0023] Figure 6 is a cross-sectional view of a leading edge 12 of fan blade 10 in an alternate embodiment. The embodiment of Figure 6 is similar to that in Figure 5, but only selected fiber composite layers are replaced with high elongation fiber composite strips 22. Thus, a fiber composite layer is interposed between the high elongation fiber composite strips 22 rather than contiguous high elongation fiber

composite strips of Figures 2-5. High elongation fiber composite strips 22 have fibers oriented in a direction 45 degrees relative to the spanwise direction of the blade 10. The high elongation fiber composite strips 22 meet the fiber composite layers at a joint as described above with reference to Figure 3.

[0024] Figures 7-10 are cross-sectional views of fan blade 10 depicting different positions for the high elongation fiber composite strips. Figure 7 depicts the high elongation fiber composite strips at the leading edge 12 of fan blade 10. Figure 8 depicts the high elongation fiber composite strips at the leading edge 12 and trailing edge 14 of fan blade 10. Figure 9 depicts the high elongation fiber composite strips at the trailing edge 14 of fan blade 10. Figure 10 depicts the high elongation fiber composite strips across the entire surface of fan blade 10. The thickness of the high elongation fiber composite strips may vary over the surface of the fan blade.

[0025] Figure 11 is a cross-sectional view a leading edge 12 of a fan blade in another embodiment of the invention. As shown in Figure 11 blade 10 includes a reinforcement 30 which is a metal guard secured to the leading edge. It understood that the reinforcement 30 may be positioned at one or more of the leading edge, trailing edge and tip and may be made from materials other than metal. In addition a coating 32 is shown on the first surface 16, but may be applied on one or both of the first surface 16 and second surface 18. Coating 32 may be an erosion protection coating, paint, etc.

[0026] In an exemplary embodiment, the same resin system is used for the fiber composite layer and the high elongation fiber composite strips. The resin microstructure may be tailored to produce higher fracture toughness at the joint between a high elongation fiber composite strip and a fiber composite layer. A high damping material may be used either as a resin or as an interlayer between fiber composite layers. Further, undulating or angled layer configurations may be used to augment damping.

[0027] The combination of high elongation fiber composite strips used in conjunction with fiber composite layers provides increased mechanical integrity. This

hybridized material system increases the interlaminar fracture resistance relative to single material systems. The high elongation fiber composite strips are lightweight relative to metal leading edges which provides a reduced airfoil thickness resulting in better aerodynamic performance and improved foreign object damage resistance.

[0028] While the invention has been described with reference to a preferred embodiment, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.